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A novel approach for evaluating level, frequency and duration of lumbar posture simultaneously during work

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Objectives Electrogoniometers are used to collect continuous information on postural distributions among workers. Enormous quantities of data are generated that have to be reduced to meaningful parameters (angle, frequency, and duration). In this study we propose statistical models to determine these essential characteristics of postural load on nurses, housekeepers, and office workers.

Methods A direct registration of the lumbar posture was made over a workday with an inclinometer. An exposure variation analysis was used to summarize information on the angle of trunk flexion, the time period of maintained postures, and the percentage of worktime in a data matrix. A hierarchical regression analysis was used to compare these characteristics among nurses (N=64), housekeepers (N=16), and office workers (N=27).

Results The occupational groups did not differ for either frequency or duration of trunk flexion over 30 degrees since frequency and duration were inversely related. Nurses experienced longer worktimes than the office workers did for trunk flexion between 30 and 70 degrees maintained < 5 seconds, whereas office workers experienced longer worktimes in smaller angles (< 30 degrees) for longer periods. Comparable differences in the distributions of postural load were found between housekeepers and office workers.

Conclusions This study describes the use of hierarchical models in analyses of the exposure level, frequency, and duration of postural load simultaneously and offers an alternative to conventional ergonomic analysis in which the dynamics of exposure are often ignored. The distinction in postural load between nurses or housekeepers and office workers is best determined by the combination of trunk angle and time period.

Key terms epidemiology, ergonomics, exposure, hierarchical regression, multilevel model, physical load, variation.

Low-back pain constitutes a major health problem in many occupational populations. Despite the evidence associating low-back pain with a variety of work activities and risk factors (1, 2), dose-response relations between mechanical load at work and low-back pain are far from clear. The lack of quantitative data on these relationships may be explained to a large extent by poor exposure characterization (3). In order that dose-response relations between mechanical load and low-back pain can be studied and effective ergonomic improvements can be instituted, attention needs to be directed towards the quantitative characterization of mechanical load that describes both exposure patterns and factors affecting the exposure patterns. In contrast to the usual concept in occupational epidemiology whereby exposure refers to an agent external to the worker, in musculoskeletal epidemiology the workers' interaction with the workplace plays a crucial role in exposure characterization (ie, physical load cannot be determined independently of the worker) (4).

Observational methods and direct measurement techniques are increasingly being used in musculoskeletal epidemiology. Direct measurements are focused on specific components of physical load. A major advantage of direct measurement techniques in comparison with subjective judgments or observations is their precision and accuracy, as well as their informational content. However, the enormous amount of data has to be reduced before it is interpretable in epidemiologic studies. Mathiassen & Winkel (5) have proposed an exposure variation analysis (EVA) whereby the available data are reduced to a limited number of essential

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parameters by which the exposure pattern is still sufficiently captured. The essential information on the level, frequency, and duration of the exposure parameter of interest is summarized in a data matrix. In spite of the usefulness of the quantitative presentation of exposure in essential parameters using this analysis, there is a clear need for a statistical method by which the data matrices of the analysis can be analyzed (ie, to analyze data matrices formally among different groups of people).

Before the data matrices of an exposure variation analysis can be analyzed formally, it has to be noted that successive combinations of level, duration, and frequency in the matrix are correlated. A comparison can be made with small area studies. The assumption in small area studies is that the variation in standardized mortality rates among neighbor areas is smaller than among areas further apart. To improve and stabilize these rates, a hierarchical regression approach can be used, by which a second-stage model pulls the estimates of neighbor areas towards each other (6, 7). In our present study, we proposed an analogous approach to analyzing exposure patterns that are presented in data matrices of the exposure variation analysis. In particular, the estimates of the ordinary regression model — which describes exposure level, duration, and frequency simultaneously — have been improved with the use of a second-stage model. The second-stage model incorporates a priori information on similarities among different classes of exposure level and exposure time periods.

In our study we determined the essential characteristics of postural load among nurses, housekeepers, and office workers. This information can be of great value within the framework of epidemiologic studies on postural load and musculoskeletal disorders.

Subjects and methods

Data collection

The subjects in our study participated in a large epidemiologic study among nursing home personnel. The original study population consisted mainly of nurses, assistant nurses, home care workers, and office workers. For the present study 64 nurses and assistant nurses, 16 housekeepers, and 27 office workers were included.

The exposure pattern of trunk flexion in the sagittal plane as a function of time at the workplace was measured by means of an electrogoniometer. This electrogoniometer was attached to the trunk at L2-L3, while the angular position of the trunk was recorded with a frequency of 16 Hz for 8 hours (8). An exposure variation analysis (table 1) was used to summarize this enormous amount of data (about 460 000 data points per subject) in a data matrix for each subject. The exposure level (trunk angle) was grouped into nine different classes of 0–10 degrees ranging from 0 degrees to greater than 80 degrees of flexion. The time period of the trunk posture (as a representation of frequency) in a particular angular class was grouped into five classes with cut-off values of 1, 2, 5, and 10 seconds. The matrix consisted of 45 combinations (cells) of exposure level and time period. The percentage of worktime spent in each cell is presented. It should be noted that the three parameters exposure level, time period, and percentage of worktime are interrelated.

Table 1. Matrix of an exposure variation analysis (EVA) for a given subject with the percentage of worktime (the number in each cell) for different angles of trunk flexion and different periods of sustained trunk flexion. (° = degrees)

	Trunk flexion								
Time period	0-10°	10-20°	20-30°	30-40°	40-50°	50-60°	60-70°	70-80°	>80°
0- 1s	31.45	23.32	5.85	2.50	1.27	0.77	0.71	0.47	0.27
1- 2s	4.70	7.70	2.11	0.41	0.18	0.09	0.04	0.12	0.01
2- 5s	0.61	1.30	0.21	0.08	0.03	0.01	0.01	0.01	0.00
5-10s	0.51	1.32	0.19	0.07	0.03	0.01	0.00	0.00	0.00
>10s	0.29	0.37	0.09	0.02	0.00	0.01	0.01	0.00	0.00

Data analysis

Exposure level, time period, and percentage of worktime were simultaneously described using a log-linear model (equation 1). The elements of observation were the cells within a data matrix, with the percentage of worktime as the outcome variable. [There were 45 cells in each matrix for every one of the 107 subjects, totaling 4815 observations.] To capture the complete exposure pattern described by combinations of the nine levels of exposure and the five levels of the time period, 45 dummy parameters were included in the model without any intercept. In this way, the expected percentage of worktime in each cell of the matrix was determined by the model. Furthermore, the interaction of occupation (nurse or housekeeper versus office worker) and parameters of the exposure pattern were entered into the model:

$$\text{Log } w = E\beta + I\varphi, \qquad \text{[equation 1]}$$

where column vector w contains the percentage of worktime for the given combination of trunk angle and time period in cell c (c=1,..., 45) for subject j (j=1,..., 107). w consists of 4815 (=107·45) elements. Matrix E consists of 4815 rows and 45 columns. The columns of E are dummy variates d (d=1,..., 45) corresponding to the 45 cells describing the combinations of trunk angle and time period. The 4815 rows of E define the value of dummy variate d in cell c for subject j. Matrix I defines

the interaction between a co-factor (occupation) and the exposure pattern of trunk flexion. I consists of 4815 rows and 45 columns, the elements of I for subject j are obtained by multiplying the elements of E for subject j with a value of 1 or 0 of a dichotomous variable depending on the occupation of subject j. $\beta = (\beta_1,\ldots, \beta_{45})'$ is the column vector of the log-linear regression coefficients corresponding to the 45 dummy variates, $\varphi = (\varphi_1,\ldots, \varphi_{45})'$ is the column vector of the log-linear regression coefficients corresponding to the 45 interactions between exposure pattern and occupation. Since the group effect of the occupation was not entered in the model, the interaction factor reflects the differences in the percentage of worktime for a given combination of level and time period between the different occupations. For the interpretation of φ, these parameters were transformed to create relative worktimes [RWT = exp(φ)]. The RWT represents the ratio of the percentage of worktime for a given combination of trunk angle and time period among the occupational groups. For example, a RWT of 2.00 for nurses means that the percentage of worktime for a certain angle and time period among nurses is two times higher than the percentage of worktime among the office workers.

Fitting model 1 using conventional maximum likelihood has some drawbacks. First, it does not take dependencies of the observations into account. Here, there are dependencies among cells in the matrix. When a subject has worked on a certain level for a while, he or she will inevitably change from it to one of the neighbor classes; it is not possible to skip some classes. Hence, a spatial correlation pattern can be assumed (ie, the correlation between neighbor cells in the matrix is stronger than the correlation between cells further apart). A second disadvantage is that the large number of parameters in the model may limit the ability to obtain accurate coefficient estimates (9, 10).

One way to overcome the first drawback (ie, to take the dependencies of the cells into account) is to include a random effect that is a coefficient for the sets of repeated observations of single individuals. However, such a model will not overcome the second drawback of less accurate estimates.

To overcome the second drawback of model 1, a multilevel model can be used, as illustrated by several authors (10–15). Such a hierarchical approach will provide estimates of model 1 that are more stable and accurate as a result of a priori defined similarities among the coefficients. In our study this approach was used, since the limited number of observations in some combinations of exposure level and time period resulted in imprecise estimates with model 1.

Since the main interest is the interaction factors φ, which reflect the relative worktimes for the different categories of exposure level and time periods, it is only necessary to improve the coefficients φ with a second-stage model (and not the coefficients β):

$$\text{Log } w = E\beta + I\varphi \quad \text{(first-stage model)}$$

$$\varphi = Z\pi + \varepsilon \quad \text{(second-stage model),} \quad \text{[equation 2]}$$

where, as in model 1, φ is the column vector of log-linear regression coefficients corresponding to the 45 interactions between the exposure pattern and the co-factor. Matrix Z consists of 45 rows and 15 columns. Z contains the second-stage covariates for the interaction between the exposure pattern and co-factor. The second-stage covariates are 15 dummy variables corresponding to 15 clusters of interdependent cells. [See figure 3, in the results section, where the dashed lines separate 15 clusters of cells.] π is a column vector of coefficients responding to the effects of second-stage covariates on the coefficients φ, and the elements of e are independent normal random variables with zero means and variances τ^2. Since design matrix Z defines which cells are a priori comparable (the cells within a cluster) and because, for each cell, there is a coefficient φ (from model 1), the second-stage model defines which coefficients φ are a priori comparable (the coefficients of cells within a cluster). The justification for introducing these similarities among cells within a cluster is based on the fact that subjects can only move from one cell to a neighbor cell and not to any other cell in the matrix. Hence, with this multilevel model, the estimates of φ from model 1 for cells close to each other in space (ie, within a cluster) are shrunk towards each other and, consequently, will result in smaller and more stable estimates (12, 14, 15). It has to be noted that this novel approach in model 2 does not take into account the issue of repeated observations of single individuals.

To perform the hierarchical regression, a two-step procedure was used, as described extensively by Witte & Greenland (14, 16). In the first step the parameters of model 1 were estimated using the GENMOD procedure available with SAS (statistical analysis system) statistical software (SAS Inc, Cary, North Carolina, United States) (16). In the second step the hierarchical model was fit with a modified program of Witte et al (16) written in the IML procedure using a weighted-least-squares method. The coefficients π were estimated using a weighted-least squares-method (10) with weights derived from the covariance matrix of φ from the maximum-likelihood estimation of the first-stage model and the variances of the RWT values in different cells, taking into account the cluster effect. The variances (τ^2) of the RWT values were constrained with a semi-Bayes approach in order to introduce more stable estimates. When the vector of variances equals 0, it implies equal RWT values among the combinations of exposure level and time period within one cluster of cells. Large prespecified values of t result in less shrinkage towards the

prior RWT values, whereas small values of t result in more shrinkage (12, 14, 15). We set the standard deviations τ to modest values (0.32), which implies 95% a priori certainty that the differences in the RWT values between the cells within a cluster lie within a exp $(3.92 \cdot 0.32) = 3.5$-fold range (eg, 0.5 to 1.75).

Results

Differences in trunk flexion between the nurses, housekeepers, and office workers with the traditional approach

In figure 1 the distribution of worktime is presented over trunk flexion categories in a traditional way in the field of ergonomics. Distinct differences between the nurses, housekeepers, and office workers were seen for trunk angles between 0 and 10 degrees. A major disadvantage of this traditional approach, for both presentation and analysis, is that the focus is on exposure level and duration and that exposure frequency is not taken into account (ie, the percentage of worktime spent in each trunk angle is totaled over the different classes of exposure time period, whereby the dynamics of trunk flexion are ignored).

Differences in exposure pattern between the nurses, housekeepers, and office workers with the level, time period, and percentage of worktime

Figure 2 summarizes the results of fitting the hierarchical regression model by which the ratios of the percentage of worktime are presented for classes of trunk angle and exposure time period for nurses and office workers (RWT). It is shown that the nurses experienced significant longer worktimes in trunk flexion between 0 and 70 degrees for periods of < 5 seconds. The largest relative worktimes were found between 30 and 70 degrees of flexion for 0–5 seconds, the RWT values varying from 2.13 (95% CI 1.26–3.58, for 30–40 degrees and 2–5 seconds) to 2.66 (95% CI 1.19–5.94, for 50–60 degrees and 2–5 seconds). For an exposure time period of > 5 seconds, the office workers experienced longer worktimes in trunk angles up to 30 degrees.

When the housekeepers and office workers were compared (figure 3), the RWT values indicated that the housekeepers experienced significantly longer worktimes in trunk flexion between 0 and 80 degrees for periods of up to 5 seconds. The largest relative worktimes were found between 30 and 80 degrees, the RWT values varying from 4.25 (95% CI 1.28–14.17, for 70–80 degrees for < 1 second) to 2.85 (95% CI 1.59–5.12, for 30–40 degrees and 2–5 seconds). Furthermore, the

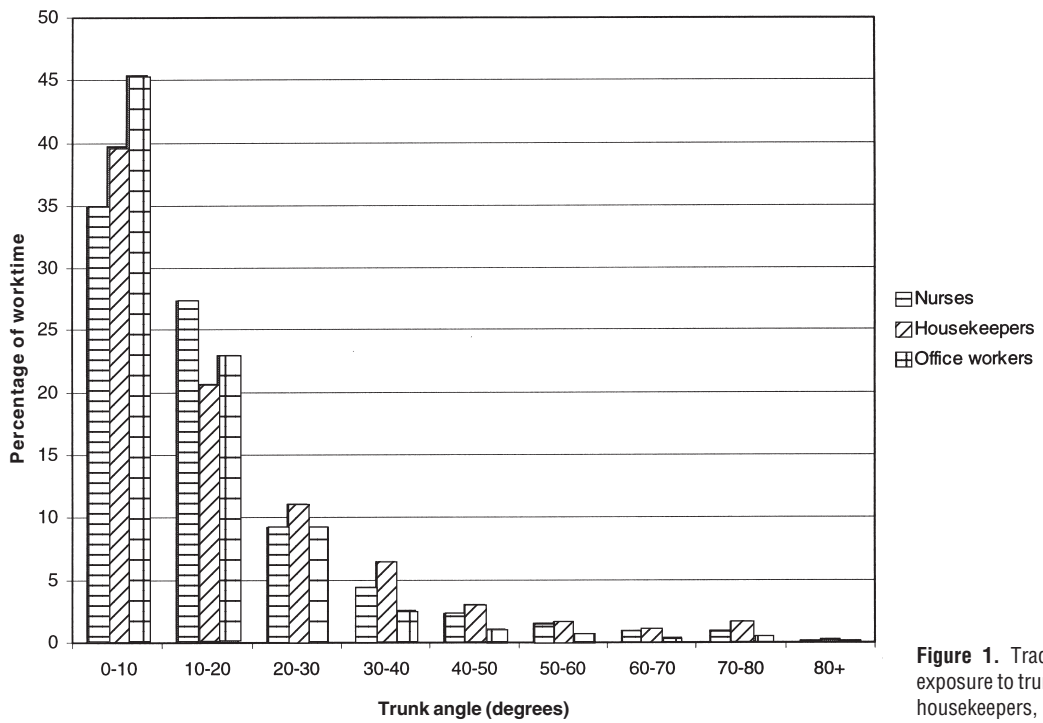

Figure 1. Traditional approach to exposure to trunk flexion for nurses, housekeepers, and office workers.

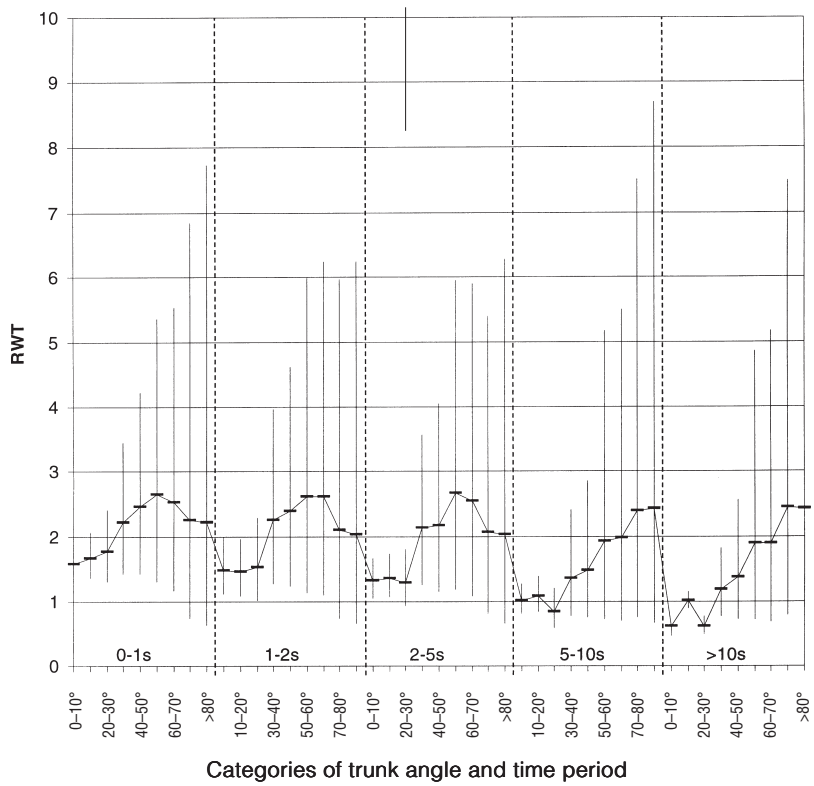

Figure 2. Differences in the percentage of worktime between the nurses and office workers, expressed in relative worktime (RWT) and 95% confidence intervals. (° = degrees)

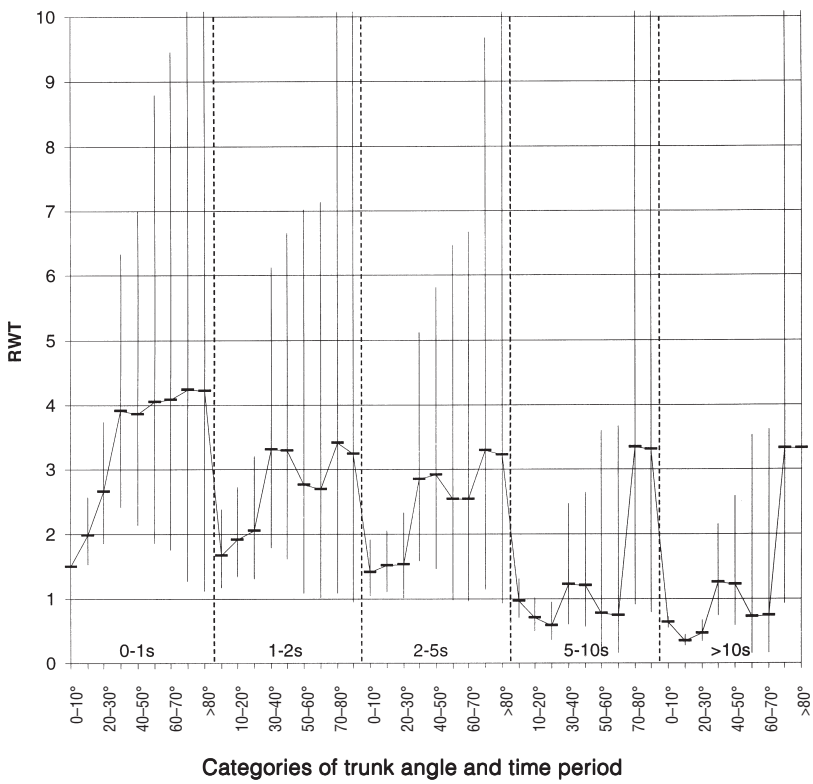

Figure 3. Differences in the percentage of worktime between the housekeepers and office workers, expressed in relative worktime (RWT) and 95% confidence intervals. (° = degrees)

housekeepers experienced lower frequencies in trunk flexion between 0 and 30 degrees for periods of ≥5 seconds.

Figure 4 shows the dynamics of trunk flexion of the occupational groups. It can be seen that the nurses and housekeepers showed longer worktimes in the upper right half of the matrix, which reflects dynamic work. The lower left half of the matrix reflects more static work, the office workers experiencing the longer worktimes in that area.

Discussion

It is well known that the dynamic and static aspects of postural movements are important in explaining why physical load may cause musculoskeletal problems (3–5). Hence exposure characterization of physical load should take into account the three essential parameters of any exposure parameter, level, frequency, and duration. Traditionally, emphasis is placed on the level of exposure. [See figure 1.] The frequency of the exposure parameters (ie, the changes from one exposure level to another) is seldom presented (17). In principle, real-time registration of angular trunk position acquired through direct measurement techniques allows for a quantitative description of all three of the essential parameters of exposure. The question that arises is how this amount of information can be used within the framework of epidemiologic studies on postural load and musculoskeletal problems. More specifically, the main interest is to reduce the data and subsequently identify the relevant aspects of the exposure pattern (in terms of level, frequency, and duration) to be applied in epidemiologic designs. The enormous amount of data acquired with direct measurement techniques can be reduced with processing using the exposure variation analysis, by which the parameters level, frequency, and duration are still captured. Subsequently, to identify relevant aspects of the exposure pattern, the obtained data-matrix of the analysis must be evaluated within the existing body of epidemiologic knowledge. In our study, postural load data from three occupational groups were evaluated. The a priori epidemiologic knowledge concerning nurses and office workers was, first, that nurses experience higher proportions of back problems, and, second, postural load is a known risk factor for back problems. Hence it is reasonable that exposure parameters as extracted by the exposure variation analysis are risk-indicative. More specifically, with matrices of this analysis, the epidemiologic relevant aspects of postural load in terms of level, frequency, and duration can be identified. However, valid statistical techniques are a requisite.

In our study we proposed models for analyzing exposure patterns whereby the three essential parameters exposure level, frequency, and duration are taken into account simultaneously. The analyses demonstrated that the nurses and housekeepers spent a significantly larger amount of their worktime in larger trunk angles in combination with shorter time periods than office workers did; the office workers spent a larger amount of their worktime in smaller angles for longer time periods. In other words, nurses and housekeepers are exposed to more dynamic work with more trunk flexion, whereas office workers perform static work. The pattern of the lumbar posture of the nurses and housekeepers in reference to the office workers differed the most strongly for worktime in trunk flexion between 30 and 80 degrees for periods of <5 seconds. Furthermore, it was shown that the nurses (and housekeepers) cannot be discriminated from office workers on the basis of worktime with trunk flexion of >30 degrees because the (relative) worktimes for these angles are strongly dependent on the exposure time period (see figures 2 and 3); the differences in time period and the percentage of worktime may offset each other, thereby presenting a seemingly similar level of physical load. This possibility means that the often adopted measure of exposure — percentage of

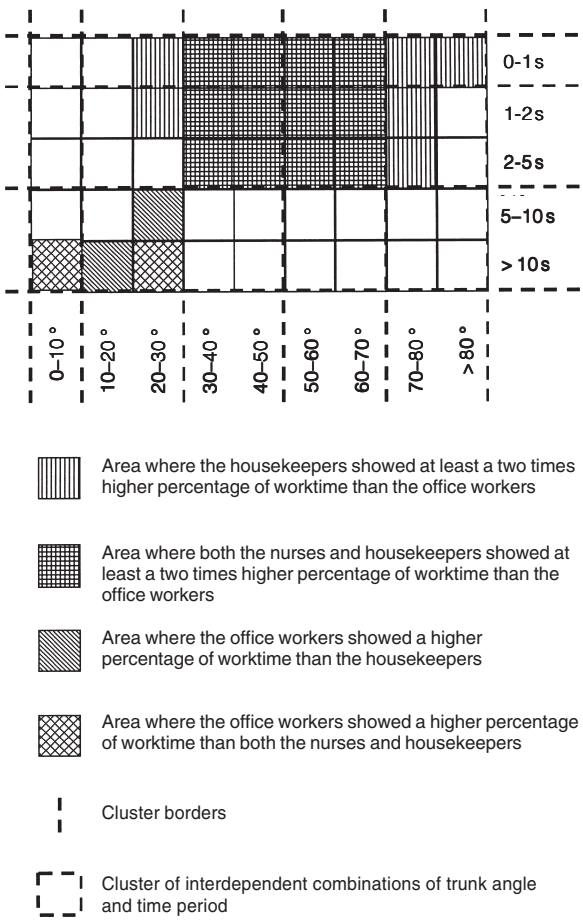

Figure 4. Dynamics of the lumbar posture. (° = degrees)

worktime with a cut-off of 20 degrees of flexion, which ignores frequency — does not discriminate between nurses (or housekeepers) and office workers. When observations at the workplace are chosen to characterize physical load, it is practically impossible to characterize both level (trunk angle) and time period (two observers are needed, one for level and one for time period). In our study, an alternative would have been to choose for observations with a cutoff of 30 degrees for the exposure level and ignore time period, since the RWT for a given angle was only moderately influenced by the time period of exposure. However, due to the fact that above 30 degrees of flexion, a smaller percentage of worktime is found, the number of observations carried out has to be increased dramatically before valid estimates are obtained when the aim is to discriminate between nurses (or housekeepers) and office workers on the basis of the percentage of worktime in trunk flexion. This conclusion can also be drawn from figures 2 and 3, since, in angles over 30 degrees, the confidence intervals are very large, and therefore reflect large interindividual differences for these angles.

An important feature of the statistical models applied is that determinants of the exposure pattern factors were taken into account. These models, in combination with an exposure variation analysis, are very powerful in the fields of ergonomics and epidemiology. They can be used to search for optimum cutoff points in exposure patterns among different work groups or among people with and without musculoskeletal problems. Furthermore, it offers possibilities to create job-exposure matrices. Dependencies among exposure level, time period, and the percentage of worktime are defined by the parameters of the model and can be presented conditionally for job titles. Furthermore, the combination of angle, time period, and the percentage of worktime allows a quantitative definition of the concepts static and dynamic work and can be presented graphically, such as in figure 4. This definition of static and dynamic work allows an even further reduction of the data and provides possibilities to define the essential parameters concerning the dynamics of work that can be included in epidemiologic designs.

As shown in our study, the advantages of statistical models in combination with exposure variation analyses are clear. As mentioned earlier, conventional regression analyses do not take the dependencies among neighboring classes of exposure level and time period into account. One way to adjust for this effect is to use a random effects model. The disadvantage of such a model is that it may result in inaccurate and unstable estimates in the case of small numbers. The reason for using hierarchical regression models (model 2) is to acquire more stable estimates. Instead of all 90 of the coefficients of the first-stage model being estimated with maximum likelihood, the coefficients were modeled with far fewer parameters in the second-stage model (ie, the a priori similarities among the combinations of exposure level and time period within a cluster). In a manner comparable with disease mapping, in which mortality rates of small areas with few observations are shrunk towards the mortality rates of large surrounded areas (6, 7), in our study, unstable estimates were shrunk towards more stable coefficients of neighboring classes of level and time period within the cluster. The elements of t were the shrinkage parameters (14, 15). However, the hierarchical model does not take the correlations of neighboring observations into account. It is possible to create a hierarchical model that also includes a random subject effect to capture the dependencies. The major disadvantage is the complexity of the model, as well as the computation time necessary to estimate the coefficients. The expectation is that such a model would result in slightly larger standard errors of the estimates (assuming the same τ).

In conclusion, our study describes the use of hierarchical regression models in analyzing the exposure level, frequency, and duration of postural load simultaneously. The distinction in postural load between nurses or housekeepers and office workers is best determined by the combination of trunk angle (exposure level) and time period (frequency). The proposed statistical procedure is of use when the study groups of interest differ a priori in epidemiologically interesting aspects such as disease prevalence or when exposure parameters as extracted by an exposure variation analysis could be risk-indicative. In such cases the statistical technique proposed offers great possibilities to pinpoint the relevant aspects of the exposure of interest so that they can be used in epidemiologic designs.

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